Rapid Full-Scale Bioremediation of Perchlorate in Soil at a Large Brownfields Site

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The former Bermite site north of Los Angeles, California, was used to manufacture various explosives and related products containing energetic compounds, including perchlorate. Remediation of perchlorate in site soil and groundwater is being conducted to meet regulatory requirements and allow planned redevelopment activities to proceed. The general approach to perchlorate remediation of shallow soil at the site includes excavation of affected soils followed by ex situ bioremediation. Glycerin was chosen for use as an electron donor because of its stability, safety, low cost, and regulatory acceptance. However, full-scale bioremediation operation with glycerin initially resulted in inconsistent results despite consistent perchlorate biodegradation observed in treatability study microcosms. To eliminate the inconsistency and optimize the biotreatment process, additional studies were performed in the field on parallel tracks to determine crucial factor(s) that influenced inconsistent breakdown of perchlorate in site soils. Total Kjeldahl nitrogen (TKN) was determined to be a significant factor limiting perchlorate biodegradation. The addition of di-ammonium phosphate (DAP) resulted in the consistent and complete perchlorate removal, generally within two weeks of incubation with a median destruction rate of about 200 µg/kg/day. Soil processing rates were gradually increased over the year, and, by the summer, approximately 2,000 to 2,500 tons of soil were being processed per day with a total of approximately 160,000 tons processed by the end of July. The total unit treatment cost for the process is about approximately $35/ton. The glycerin-DAP process is playing a major role in the remediation of this 1,000-acre former industrial site. © 2008 Wiley Periodicals, Inc.

INTRODUCTION

The 996-acre former Bermite site north of Los Angeles, California (Exhibit 1) was used from 1934 to 1987 to manufacture various explosives and related products containing energetic compounds. Historic site operations included design, development, formulation, fabrication, and assembly of explosives, propellants, and pyrotechnic devices; and for testing of Sidewinder and jet-assisted takeoff (JATO) rocket motors. This site is now undergoing remediation to meet the requirements of the California Department of Toxic Substances Control (DTSC), the lead regulatory agency.

Some of the products used at the site included perchlorate salts, and, consequently, perchlorate contamination of soil and groundwater has occurred at several locations at the
Exhibit 1. Former Bermite facility location

site. Perchlorate is known to inhibit iodide uptake by the thyroid (US EPA, 2005a), and because of its potential adverse health effects, remediation of perchlorate in site soil and groundwater is being conducted to meet regulatory requirements and allow redevelopment activities to proceed. The perchlorate contamination that resulted from historic operations is present in shallow soils at a number of locations. In a few locations, the perchlorate impact extends to deeper soils reaching depths of 200 feet below ground surface or more. The lateral and vertical extent of perchlorate contamination has been studied and is adequately characterized. Perchlorate concentrations in soil are highly variable and have been observed as high as 316,000 µg/kg. It is anticipated that at least 400,000 tons of shallow soil at the site may require excavation and treatment for perchlorate to meet applicable risk-based concentrations depending on future land uses at the site.

The general approach to perchlorate remediation of shallow soil at the site includes excavation followed by ex situ bioremediation. Soil washing was found to be effective for perchlorate removal and was also considered for remediation of site soils. However, this remediation technique was not selected for implementation because of issues related to the large volumes of water needed, treatment requirements for the wastewater, and the
superior performance and cost-effectiveness of the bioremediation process. In situ
treatment of shallow soil was not practical because of the widespread nature of the
perchlorate contamination, and the rolling topography. However, in situ processes, such
as gaseous electron donor injection technology (GEDIT) and bioflushing, are currently
being evaluated for use in deeper soils at the site (Evans & Trute, 2006).

Ex situ bioremediation of perchlorate in soil has been practiced since the late 1990s
and early efforts involved addition of natural organic substrates, such as mulch and
manure, to stimulate anaerobic biodegradation of perchlorate (Interstate Technology and
Regulatory Council [ITRC], 2005; US EPA, 2005b). Later, the use of alternative
amendments, including calcium magnesium acetate, ethanol, and acetic acid was
implemented to reduce the bulking associated with natural organic substrates. (GeoSyntec
Consultants, 2004; Nozawa-Inoue et al., 2005; Nzengung et al., 2001; Smith et al.,
2003). All of these processes are ultimately based on anaerobic biological reduction of
perchlorate to chloride ion by perchlorate-reducing bacteria. These bacteria are
ubiquitous in the environment, use perchlorate as a terminal electron acceptor for growth
and energy, and require the presence of an electron donor to drive perchlorate reduction
(Coates et al., 1999; Logan, 2001; Waller et al., 2004).

While many of these ex situ bioremediation approaches have been demonstrated to be
successful, attainment of nondetectable perchlorate concentrations in soil was not
required at the former Bermite site. In addition, the mass of soil to be treated at most sites
does not approach the magnitude of what is required at the Bermite site. Therefore, the
implemented bioremediation process must be rapid, reliable, efficient, and cost-effective.
While perchlorate bioremediation is becoming more and more commonplace, challenges
still exist, as is demonstrated in this case study. Recognition and resolution of these
challenges was important with respect to facilitating the large-scale remediation to meet
regulatory requirements and expedite potential future redevelopment of this site.

MATERIALS AND METHODS

Microcosm Tests

Microcosm tests were conducted in eight-ounce glass jars packed with amended site soil.
Soil was amended with various electron donors at equivalent chemical oxygen demand
(COD) concentrations and the moisture content was adjusted to 16 percent. The electron
donors evaluated included high-fructose corn syrup, or HFCS (500 mg/kg); molasses
(500 mg/kg); glycerin (450 mg/kg); acetic acid (500 mg/kg); and isopropanol
(250 mg/kg). Replicate jars were prepared and harvested, and analyses of perchlorate
concentrations were conducted at various time intervals.

Full-Scale Process

The full-scale process consisted of the following unit operations: (1) soil excavation; (2)
rock screening (to remove two inches plus size fraction); (3) rock crushing; (4) pug mill
mixing of soil, crushed rocks, water, glycerin, and DAP (Exhibit 2); (5) bioremediation
incubation in Ag-Bag® (Exhibit 3) or concrete containment (Exhibit 4) cells; and (6) soil
drying. The screener and rock crusher included a Powerscreen Powergrid Impact Crusher
and Pegson 249 Mobile Impactor. The pug mill was a Cedar Rapids model 828 with a
Exhibit 2. Pug mill operations showing loading of hopper/conveyor to pug mill (A) and discharge of amended soil from pug mill (B)

maximum soil processing capacity of 300 tons per hour. Water, glycerin, and DAP were added using a custom automatic metering system that operated using a load cell on a conveyor to continuously measure the mass rate of soil being conveyed to the pug mill. The flow rates of water, glycerin solution, and DAP solution were automatically controlled using a proportional-integral-derivative (PID) controller. The load cell provided the process variable input, set points were entered manually, and control variable outputs were sent to metering pumps to achieve desired concentrations of moisture, glycerin, and DAP in the soil following mixing. The Ag-Bag system has been designed originally to support agricultural activities and is typically used for containment of hay or silage. It consists of an elongated flexible low-density polyethylene bag (EcoPOD manufactured by Ag-Bag of St. Nazianz, Wisconsin) that is approximately 10 feet in diameter by 200 feet long with a storage capacity of 375 cubic yards or 500 tons of soil. The bags were filled with a CT-10SL compost system by Ag-Bag that had a processing capacity of over 3 tons per minute. The Ag-Bag system provides full enclosure and
Exhibit 3. Ag-Bag operations showing loading of CT-10SL compost system (A), EcoPOD being filled by CT-10SL (B), filled EcoPOD (C), and multiple EcoPODs containing soil undergoing treatment (D)
Exhibit 4. Containment cell operations showing loading of containment cells (A) and filled and covered containment cells undergoing treatment (B)

containment of soil while it is undergoing incubation and treatment; thus, it is a favorable method where full containment of chemically impacted soil is desired. In addition to the Ag-Bags, a number of concrete cells were constructed to increase the treatment capacity. The concrete containment cells were built using interlocking concrete blocks, and each cell measured 25 feet wide by 115 feet long by 5 feet high. The concrete containment cells were underlain with asphaltic concrete and covered with plastic tarps to prevent drying and air intrusion.

Glycerin was delivered to the site in pure form and was diluted slightly with 10 percent water by volume prior to use to reduce viscosity and facilitate pumping. The target glycerin concentration was 500 mg/kg. Di-ammonium phosphate was dissolved in potable water to make a solution containing 140 g/L. The target DAP concentration in soil was 50 mg-N/kg but ranged from 50 to 100 mg-N/kg in practice. Soil typically contained 6.7 \pm 2.5\% (i.e., one standard deviation) moisture prior to processing. Water was added to result in about 15 to 17 percent moisture content.
Exhibit 5. Analytical methods

<table>
<thead>
<tr>
<th>Analyte</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perchlorate</td>
<td>EPA 314.0</td>
</tr>
<tr>
<td>Chemical Oxygen Demand (COD)</td>
<td>EPA 410.4</td>
</tr>
<tr>
<td>Total Kjehldahl Nitrogen (TKN)</td>
<td>SM 4500N Org B or EPA 351.3</td>
</tr>
<tr>
<td>Metals</td>
<td>EPA6010B</td>
</tr>
<tr>
<td>pH</td>
<td>EPA9045C</td>
</tr>
<tr>
<td>Moisture</td>
<td>ASTM D2216 or EPA 160.3</td>
</tr>
<tr>
<td>Total Phosphorous</td>
<td>EPA 365.3</td>
</tr>
<tr>
<td>Ortho-Phosphorous</td>
<td>EPA 365.3</td>
</tr>
<tr>
<td>Nitrate</td>
<td>EPA 300.0</td>
</tr>
<tr>
<td>Nitrate</td>
<td>EPA 300.0</td>
</tr>
<tr>
<td>Volatile Fatty Acids</td>
<td>Ion Chromatography</td>
</tr>
</tbody>
</table>

Microcosm and Field Test Sampling and Analysis

The microcosm soil was analyzed for perchlorate, nitrate, moisture, pH, and COD by STL of Los Angeles, California, using methods shown in Exhibit 5. Jars were sent to the laboratory overnight on ice for analysis.

For full-scale operations, grab soil samples were collected during processing prior to and after mixing of the amendments in the pug mill. Soil samples from Ag-Bags and containment cells were collected with a hand auger along the length of the bag or cell so that approximately one sample per 125 tons was collected.

Volatile fatty acids were analyzed by ion chromatography at BioInsite of Murphysboro, Illinois.

Other laboratory analyses of samples collected from the site were conducted by STL from May to December 2006 and by Advanced Technology Laboratories of Signal Hill, California from December 2006 onward. Exhibit 5 lists the analyses and analytical methods used for this study. With the exception of soil moisture, all analyses were conducted on distilled water extracts of soil samples.

RESULTS AND DISCUSSION

Acetic acid was initially chosen for use in the bioremediation process based on its rapid biodegradability, previous use, and reported success in removal of dissolved perchlorate from water in bioreactors (Min et al., 2004) and low cost (e.g., March 2006 quotation from L.A. Chemical for $0.465/lb for a 50 percent solution). Use of acetic acid in the field was initially successful, but expanded use in a variety of soils and in large volumes gave inconsistent results with respect to perchlorate removal. Large-scale use of acetic acid also created nuisance odors for the workers onsite; consequently, additional microcosm studies were conducted to evaluate alternatives to acetic acid (Exhibit 6). The results confirmed the inconsistency of perchlorate removal with acetic acid and indicated that several other electron donors, including HFCS, glycerin, and isopropanol would be suitable.
Glycerin was chosen for use because of its stability, safety, low cost (e.g., May 2006 quotation from L.A. Chemical for $0.585/lb for a 99.5 percent solution), and regulatory acceptance. Isopropanol was eliminated because it is flammable, and its use would require an air permit from the California South Coast Air Quality Management District (SCAQMD). High-fructose corn syrup was eliminated from use because it is perishable and may produce inconsistent results with respect to perchlorate biodegradation. The only engineering issue with respect to glycerin is its relatively high viscosity of 1,400 cP at 20°C, which can make pumping more difficult. This handling issue was easily remedied by addition of 10 percent water by volume, which reduced the viscosity to 220 cP at 20°C.

Full-scale operation with glycerin was initiated and resulted in inconsistent perchlorate breakdown despite consistent perchlorate biodegradation observed in the treatability study microcosms (Exhibit 7). A total of 56 Ag-Bags and one containment cell were filled with soil that contained perchlorate ranging in concentration from 470 to 10,000 µg/kg. Perchlorate removal from soil ranged from 26 percent to 100 percent with an average concentration reduction of 78 percent following an incubation period of
Exhibit 8. Correlations between perchlorate removal and various parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$r^2$</th>
<th>Correlation$^a$</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propionic acid</td>
<td>0.60</td>
<td>+</td>
<td>21</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.59</td>
<td>+</td>
<td>8</td>
</tr>
<tr>
<td>Nickel</td>
<td>0.57</td>
<td>+</td>
<td>8</td>
</tr>
<tr>
<td>Copper</td>
<td>0.54</td>
<td>+</td>
<td>8</td>
</tr>
<tr>
<td>Isovaleric acid</td>
<td>0.40</td>
<td>+</td>
<td>21</td>
</tr>
<tr>
<td>Moisture</td>
<td>0.37</td>
<td>+</td>
<td>79</td>
</tr>
<tr>
<td>Lead</td>
<td>0.34</td>
<td>+</td>
<td>8</td>
</tr>
<tr>
<td>Lactic acid</td>
<td>0.33</td>
<td>−</td>
<td>21</td>
</tr>
<tr>
<td>Arsenic</td>
<td>0.27</td>
<td>+</td>
<td>8</td>
</tr>
<tr>
<td>TKN</td>
<td>0.21</td>
<td>+</td>
<td>43</td>
</tr>
<tr>
<td>Formic acid</td>
<td>0.20</td>
<td>−</td>
<td>21</td>
</tr>
<tr>
<td>COD</td>
<td>0.088</td>
<td>−</td>
<td>79</td>
</tr>
<tr>
<td>Isobutyric acid</td>
<td>0.064</td>
<td>+</td>
<td>21</td>
</tr>
<tr>
<td>Valeric acid</td>
<td>0.035</td>
<td>+</td>
<td>21</td>
</tr>
<tr>
<td>Isocaproic acid</td>
<td>0.020</td>
<td>+</td>
<td>21</td>
</tr>
<tr>
<td>Total phosphorous</td>
<td>0.0090</td>
<td>−</td>
<td>8</td>
</tr>
<tr>
<td>pH</td>
<td>0.0081</td>
<td>+</td>
<td>79</td>
</tr>
<tr>
<td>ortho-Phosphate</td>
<td>0.0058</td>
<td>−</td>
<td>8</td>
</tr>
<tr>
<td>Citric acid</td>
<td>0.0015</td>
<td>+</td>
<td>21</td>
</tr>
<tr>
<td>Cadmium</td>
<td>NA</td>
<td>All ND &lt; 0.5 mg/kg</td>
<td>8</td>
</tr>
<tr>
<td>Molybdenum</td>
<td>NA</td>
<td>All ND &lt; 4 mg/kg</td>
<td>8</td>
</tr>
<tr>
<td>Silver</td>
<td>NA</td>
<td>All ND &lt; 1 mg/kg</td>
<td>8</td>
</tr>
<tr>
<td>Cobalt</td>
<td>NA</td>
<td>All ND &lt; 5 mg/kg</td>
<td>8</td>
</tr>
<tr>
<td>Mercury</td>
<td>NA</td>
<td>All ND &lt; 0.1 mg/kg</td>
<td>8</td>
</tr>
<tr>
<td>Selenium</td>
<td>NA</td>
<td>All ND &lt; 1 mg/kg</td>
<td>8</td>
</tr>
</tbody>
</table>

$^a$ + indicates a positive correlation with perchlorate removal and − indicates an inverse relationship.

up to 65 days. Longer incubation periods led to complete removal in some but not all bags; the perchlorate removal was not consistent or predictable. The results of the initial field-scale application suggested that substitution of glycerin for acetic acid did not lead to consistent perchlorate removal from soil. Insufficient glycerin was not the reason for the inconsistent breakdown of perchlorate since the minimum, average, and maximum COD concentrations were 570, 1,100, and 2,500 mg/kg, respectively, and 300 to 500 mg/kg COD has generally been sufficient for complete perchlorate removal based on previous laboratory and field testing using site soil. A review of the effect of the moisture content revealed that insufficient moisture was not the reason for inconsistent perchlorate breakdown since the minimum, average, and maximum moisture concentrations were 15, 16, and 17 percent, respectively. A more detailed evaluation of the factors potentially affecting the perchlorate biodegradation was warranted.

Simple linear correlation coefficients ($r^2$) were calculated between percent perchlorate removal and the factors listed in Exhibit 8. Propionic acid had the greatest $r^2$
and was positively correlated with perchlorate removal. Propionic acid is a metabolite of glycerin fermentation so this correlation may be attributed to an effect of environmental conditions that are supportive of glycerin fermentation and perchlorate biodegradation rather than a direct cause of perchlorate biodegradation. Other organic acids, including isovaleric, lactic, and formic acids, also demonstrated significant correlations (i.e., defined here as $\rho$ greater than or equal to 0.20) but were either positively (e.g., isovaleric) or negatively (e.g., lactic and formic) correlated with perchlorate biodegradation. While identification of biochemical pathway(s) of glycerin fermentation was not an objective of this work, the different correlations (i.e., positive or negative) between perchlorate biodegradation and glycerin fermentation product accumulation suggest that different glycerin fermentation pathways dominated in different Ag-Bags (Dharmadi et al., 2006; Yazdani & Gonzalez, 2007). Specific environmental conditions that led to dominance of one fermentation pathway over another (i.e., propionic and isovaleric acid accumulation vs. lactic and formic acid accumulation) appear to have been a determining factor affecting perchlorate biodegradation.

Metals, including zinc, cadmium, nickel, copper, lead, and arsenic, were also positively correlated with perchlorate biodegradation. The biochemical significance of this correlation is doubtful since many of these metals can be toxic to bacteria, and few of them are significant cofactors for enzymatic reactions. Molybdenum is a known cofactor for biochemical perchlorate reduction (Chaudhuri et al., 2002); however, this metal was not detected at a concentration greater than the practical quantitation limit of 4 mg/kg. The low number of samples ($N = 8$) also reduces the dependability of these observed correlations. These correlations are likely dependent on other environmental factors or intrinsic soil characteristics that promote perchlorate biodegradation.

Moisture content and TKN were the only remaining significant factors affecting perchlorate biodegradation that needed to be thoroughly evaluated. Review of the graphical data suggested that moisture contents greater than 17 percent led to consistent and complete perchlorate biodegradation (Exhibit 9a). TKN was weakly but positively correlated with perchlorate reduction (Exhibit 9b) and moisture (Exhibit 9c). Nitrate concentrations were equal to or less than 1.2 mg-N/kg; therefore, TKN was not associated with nitrate. Nitrogen is an essential nutrient that is required for bacterial growth. Thus, nitrogen limitation can theoretically prevent or limit perchlorate biodegradation because it can limit glycerin fermentation and associated bacterial growth. Moisture is also an important environmental factor that could have altered the fermentation product distribution from propionic and isovaleric acids to lactic and formic acids. However, excess moisture (moisture contents of 17 percent and more) results in production of mud that creates logistical constraints and challenges during staging, handling, incubation, and drying steps; therefore, addition of water over 17 percent was not found to be a practical solution for the site soils. Furthermore, excessive water requires greater time and effort to dry following remediation. Therefore, addition of DAP to boost nitrogen content was evaluated as a means of increasing process stability across a range of moisture contents. Di-ammonium phosphate was selected and used to also provide a source of phosphorus that has long been recognized as an essential nutrient in promoting growth in biological systems; notwithstanding that no correlation between perchlorate breakdown and phosphorus or ortho-phosphate contents of soil was observed based on a limited number of analyses.
The addition of about 50 to 100 mg-N/kg as DAP resulted in the consistent and complete perchlorate breakdown with two exceptions (Exhibit 10). While not intentional, the data also indicate that moisture content increased slightly commensurate with addition of DAP. The positive effect of moisture in addition to that of nitrogen cannot be discounted by these data because they were positively, although weakly, correlated (Exhibit 9c). Further analysis of the data, however, clearly demonstrated that the increased TKN provided by DAP addition stabilized the process across a broad range.
of moisture content, while increasing moisture alone without DAP addition had a much less dramatic effect (Exhibit 11). The only cases where perchlorate removal was less than 90 percent with DAP addition were: (1) when the moisture content was only 13 percent and (2) during initial process start-up when glycerin and DAP amendment pumping rates were not stabilized. Therefore, although moisture content was crucial, nitrogen deficiency was the dominant environmental factor affecting perchlorate removal. While nitrogen amendment has generally not been required for \textit{ex situ} perchlorate bioremediation in other studies, suggesting that nitrogen limitation was not significant in those studies (GeoSyntec Consultants, 2004; ITRC, 2005; Smith et al., 2003; US EPA, 2005b), addition of nitrogen clearly enhanced perchlorate biodegradation in soil from this site. The site data suggest that TKN concentrations less than 100 mg/kg may be insufficient for consistent \textit{ex situ} perchlorate bioremediation in soil.

Full-scale operation with the glycerin-DAP process resulted in consistent and rapid destruction of perchlorate in soil generally within two weeks of incubation with a median

\textbf{Exhibit 10.} Full-scale results with DAP addition showing resultant TKN (A) and moisture (B)
Exhibit 11. Comparison of process stability with respect to moisture variation prior to (A) and after (B) DAP addition.

destruction rate of about 200 µg/kg/day (Exhibit 12). The rate of soil processing was also quite rapid and was limited only by the pug mill rated at 300 tons per hour. Soil processing rates were gradually increased over the year, and by the summer, approximately 2,000 to 2,500 tons of soil were being processed per day with a total of approximately 160,000 tons treated to below the 20-µg/kg cleanup level for perchlorate in excavated soil by the end of July (Exhibit 13). Rapid and consistent treatment was from January through July where the minimum, average, and maximum ambient temperatures were −1.0, 17, and 35°C, respectively.

The total unit treatment cost for the process is approximately $35 per ton (Exhibit 14). Bioremediation comprises approximately 44 percent of the total cost, and rock crushing comprises approximately 6 percent of the total cost. Current work to reduce costs is focused on developing a rock treatment process that does not involve crushing and uses bioremediation. Elimination of the rock-crushing step could reduce costs to $32/ton.
Exhibit 12. Full-scale performance of the glycerin-DAP process with respect to percentile distributions of treatment time (A) and removal rate (B).

Exhibit 13. Historical soil treatment rate and performance.
CONCLUSIONS

The bioremediation process using glycerin-DAP amendments developed for the Bermite site has rapidly, consistently, safely, and economically treated large quantities of soil containing perchlorate to nondetectable concentrations. The process successfully treated over 160,000 tons of soil over a period of seven months, which included start-up time, and has generally required two weeks of incubation time to reach nondetectable perchlorate concentrations from initial concentrations ranging from 590 to 8,400 µg/kg.

The success rate defined by percent of Ag-Bags or containment cells that attained nondetectable perchlorate concentrations was 99.3 percent. The 0.7 percent of cases (i.e., two cases) where treatment was not entirely successful and nondetectable perchlorate concentrations could not be attained were attributed to insufficient moisture (i.e., 13 percent) or unstable di-ammonium phosphate flow rates during initial start-up.

Nitrogen nutrient deficiency was discovered to be limiting process effectiveness and consistency. This limitation apparently resulted in a diversion of glycerin fermentation from propionic and isovaleric acid production to lactic and formic acid production. Moisture content above 17 percent could alleviate this limitation; however, this high moisture content would cause logistical constraints during soil staging and handling and is not practical for a full-scale process with the site soil. Amendment with DAP in addition to glycerin resulted in an efficient process that was robust with respect to typical variation in moisture contents. Moisture contents of 14 percent or greater were capable of promoting complete perchlorate destruction when DAP amendment was used. This contrasts to initial results prior to DAP amendment where moisture greater than 17 percent was required and resulted in production of mud that was difficult to handle.

The soil treatment cost of $35/ton is reasonable and has the potential for further reduction by elimination of the rock-crushing stage. Bioremediation is currently being evaluated as a means of treating the rocks without crushing. The primary challenge with treating these granitic rocks is that perchlorate appears to have diffused into the primary porosity while in aqueous solution and later precipitated during drying; thus, dissolution
and diffusion of perchlorate out of the primary porosity or diffusion of amendment into the primary porosity of these rocks will control the treatment rate.

The Bermite site is located in beautiful rolling hills north of Los Angeles, California, and is well situated for redevelopment. The glycerin-DAP process is playing a major role in the remediation of this 1,000-acre site. The process can be easily applied to other sites where large volumes of soil must be treated for perchlorate to nondetectable concentrations at a rapid pace. Nitrogen amendment may not be required for all sites; however, it is likely that nitrogen amendment can increase the consistency and rate of the process when implemented at other sites, thereby resulting in cost efficiency and accelerating the redevelopment of these sites.

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REFERENCES


Patrick J. Evans, PhD is an associate chemical engineer at CDM. He specializes in development, validation, and implementation of in situ and ex situ remediation processes. Dr. Evans is a nationally recognized remediation expert and has three patents, including one on gaseous electron donor injection technology (GEDIT) for in situ perchlorate remediation.

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William F. Grove, P.G. is a project geologist at CDM with 21 years of experience conducting and onsite management of a diverse range of hazardous waste site characterization and cleanup activities.

Hassan Amini, PhD is a principal hydrogeologist at Geomatrix Consultants. He has over 20 years of experience working on and managing soil and groundwater characterization and remediation projects. Dr. Amini directs and coordinates all technical activities related to this project and is the lead client representative and liaison with all regulatory agencies and the community.